Production Sharing, Demand Spillovers and CO_2 Emissions: The Case of Chinese Regions in GVCs

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Abstract: Recent trade literature highlights production sharing among economies (e.g., Johnson and Noguera, 2012; Koopman et al., 2014), and some studies report that 20%-25% of CO_2 emissions can be attributed to international trade (e.g., Peters et al., 2011). However, the mechanism explaining how and to what extent production sharing affects CO_2 emissions remains unclear. This study, as an extension of Meng et al. (2013a), adopts the perspective of demand spillovers to provide new insights regarding the position of Chinese domestic-regions' production in global value chains (GVCs) and their associated CO_2 emissions. To this end, we constructed a new type of World Input-Output Database (WIOD) in which China's domestic interregional input-output table for 2007 is endogenously embedded. The pattern of China's regional demand spillovers across both domestic regions and countries is revealed by employing this new database. These results were then connected to endowments theory, which helps to make sense of the empirical results. It is found that China's regions are located relatively upstream in GVCs, and had CO_2 emissions in net exports, which were entirely predicted by the environmental extended HOV model. Our study points to micro policy instruments to combat climate change: for example, tax reform for energy inputs that helps to change the production pattern, which then has an impact on trade patterns and so forth.

Keywords: Production sharing; CO_2 emissions; demand spillovers; global value chains

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1. Introduction

Today's economy is characterized by the increasing fragmentation of international production, where production sharing is the norm rather than an exception (see Johnson and Noguera, 2012; Koopman et al., 2014). This has two implications. First, intermediate goods cross borders multiple times before they are consumed by final users, meaning that increasing amounts of final goods are "Made in the World" (see WTO-IDE, 2011, and OECD-WTO, 2012) and that global value chains (GVCs) matter. Second, production-based accounting principles (say, the methods proposed in the Kyoto Protocol) for greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2) emissions, face an increasing challenge. Along with the availability of better datasets, it is possible to use alternative methods to account for CO_2 emissions according to different end-users, so that producer responsibility and consumer responsibility are distinguished (see e.g., Peters, 2008).

In fact, previous studies have tackled the problem of CO_2 emissions embodied in trade (exports, imports or both) and have reached a consensus about the latest developments (Peters and Hertwich, 2008; Peters et al., 2011). Specifically, the increase of CO_2 emissions embodied in trade seen over the last couple of years coincided with the ratification of Kyoto Protocol. However, the pattern of CO_2 emissions embodied in trade among economies and, in particular, the mechanism for their growth remains to be explained.[1] According to standard trade theory, more specialized production is usually accompanied by a larger amount of output from all relevant trading partners. It is therefore possible that production sharing will increase CO_2 emissions due to an overall growth in production. In the meantime, industry share structure may change, which may or may not contribute to CO_2 emissions. Equally important is that, due to growing output, production technology may improve (and thus the CO_2 emission intensity may fall). These effects are called the scale effect, the composition effect, and the technology effect in

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[1] Copeland and Taylor (2003) present a nice review of related literature. Temurshoev (2006) explicitly tests the "pollution haven hypothesis" and the "factor-endowment hypothesis". However, the problem of the pattern of CO_2 emissions embodied in trade and its origins has not been tackled.

the literature (see Grossman and Krueger, 1993; Levinson, 2009). Consequently, the relationship between production sharing and CO_2 emissions is unclear, which calls for a more general framework as well as empirical investigation. So, our first research question is what determines the pattern of CO_2 emissions embodied in trade among economies?

In 2013, China's total merchandise trade volume surpassed that of the United States and reached 4 trillion US dollars, making China the largest trading economy. China is the subject of intense debate about whether she should be held accountable for total CO2 emissions "on behalf of other economies that import goods from China" (see Weber et al., 2008; Dietzebacher et al., 2012). At the same time, data from the National Bureau of Statistics show that significant heterogeneity exists in regions within China, in terms of gross regional product (GRP), regional energy input intensity in production and so forth. For example, in 2013, the GRP ranged from 80.7 billion RMB (Yuan) in Tibet to 6.2 trillion Yuan in Guangdong Province. The energy input intensity difference in production is also substantial. Defined as tons of equivalent coal input per 10,000 Yuan of output, it ranged from 0.46 in Beijing to 2.28 in Ningxia Province in 2011.

On the other hand, interregional trade and production sharing among China's regions further highlight the importance of CO_2 emissions accounting in the context of GVCs. To motivate this idea, suppose there is falling external demand in the Chinese Coastal region due to a financial crisis. This shock drives down the relevant output in the Coastal region, and because some raw materials or intermediate inputs come from other regions in China, output will also contract in those regions. This is the phenomenon of demand spillover (see also Bems et al., 2010).

Similarly, CO2 emissions are embodied in interregional trade as well. More importantly, production sharing is even more pronounced among domestic regions than at international level. Meng et al. (2013a) made one of the first attempts to account for regional production sharing and the domestic interregional flow of CO_2 emissions (see also Liu et al., 2012; Qi et al., 2013; Feng et al., 2013 among others), but these studies did not fully link the domestic production chains with international production chains, thus missing one important component in the context of GVCs. In the existing literature, China's regional exports and imports are treated as exogenous rather than endogenous variables. To fill this gap in this line of study, here we utilize a novel dataset (Meng et al., 2013b) that China's domestic regions within an international input-output database. This enables us to provide a link between domestic production relationships and international production fragmentation.

To summarize, in this paper we employ a novel dataset that enables us to address the question of regional CO_2 emissions in the context of GVCs and extends the work of Meng et al. (2013a). To facilitate our analysis, the methodology of Serreno and Dietzenbacher (2010) is adopted, and more importantly, an environmental extended HOV model is employed. In so doing, we can put the results in a theoretically consistent framework and make sense of the empirical findings. Our results are relevant for policy discussions in general and, in particular, for China's Emissions Trading System (ETS) and other regional policies combating climate change.

As a first impression, China's four regions all run a surplus of CO_2 emissions in net export vis-à-vis overseas trading partners. Furthermore, upstream regions tend to be net exporters of CO_2 emissions. More interestingly, if the pattern is analyzed within the framework of the environmental extended HOV model, the direction of net CO_2 emissions flows can be entirely predicted. We suspect that this result also holds for other pollutants in a very general sense. If this is the case, it seems to suggest a resolution to the debate of "pollution haven hypothesis" vs. "factor-endowment hypothesis", as the factor endowment is the ultimate determinant of trade pattern (whether the trade is in factor content or pollutants).

The remainder of the paper is structured as follows. Section 2 presents the new methodology for the estimation of factor content of trade (and also of emissions embodied in trade) and the environmental extended HOV model. The section that follows gives a brief introduction of the construction of the novel dataset. Section 4 provides stylized facts and empirical results. The last section contains our conclusions.

2. Methodology

In this section, we develop the methodology of Meng et al. (2013a) in two respects. First, following Serrano and Dietzenbacher (2010), a demand-driven perspective is adopted, which is in the spirit of the Leontief production function.[2] Second, the extended environmental endowments theory is incorporated. By doing so, we can present richer predictions.

2.1 Modeling a full interregional input-output matrix

As shall be made clear in the data section, our novel dataset covers four regions within China along with other major economies and rest of the world (ROW). To keep things simple, the four regions within China are also considered as distinct regions. In this sense, the dataset is a full interregional input-output matrix, consisting of eight regions (including ROW).

Now we are in a position to give a formal formulation of key elements. As a starting point, consider two regions, one called Home (indexed by 1) and the other named Foreign (indexed by 2). Each region has its own production technology, endowments and pollutants. Further, it is assumed that each region has n production sectors, and each sector produces one single product (i.e., pure sectors). Each product can be used as intermediate goods either in its own region or in the other region; it can also enter into final uses, such as consumption or investment, both in its own region and in the other region. Using matrices, we can formulate the idea as[3]

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \end{pmatrix} + \begin{pmatrix} \mathbf{y}^{11} + \mathbf{y}^{12} \\ \mathbf{y}^{21} + \mathbf{y}^{22} \end{pmatrix} \tag{1a}$$

or in compact form as

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[2] Similar applications are found in the study of global value chains (GVCs): see Timmer et al. (2013, 2014).

[3] As a convention, a matrix is denoted by a bold capital letter, a (column) vector by a bold lower-case letter and a scalar by a normal weight lower-case letter. A row vector is obtained via the transposition of a column vector, and is indicated by a prime. A diagonal matrix is represented with a hat and has the elements of a vector along the main diagonal and zeros elsewhere.

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \tag{1b}$$

where $\mathbf{A}^{11}$ and $\mathbf{A}^{22}$ are intra-regional input coefficients,[4] while $\mathbf{A}^{12}$ and $\mathbf{A}^{21}$ are inter-regional input coefficients that give an indication of the extent of production fragmentation. Likewise, $\mathbf{y}^{11}$ and $\mathbf{y}^{22}$ represent final uses of local production, while $\mathbf{y}^{12}$ and $\mathbf{y}^{21}$ represent goods imported to fulfill final demand. Finally, $\mathbf{x}^{1}$ and $\mathbf{x}^{2}$ are total outputs of region 1 and region 2, respectively. Rearranging equation 1a (and equation 1b), we get

$$\begin{pmatrix}\mathbf{x}^1\\ \mathbf{x}^2\end{pmatrix} = \left(\mathbf{I} - \begin{bmatrix}\mathbf{A}^{11} & \mathbf{A}^{12}\\ \mathbf{A}^{21} & \mathbf{A}^{22}\end{bmatrix}\right)^{-1} \begin{pmatrix}\mathbf{y}^{11}+\mathbf{y}^{12}\\ \mathbf{y}^{21}+\mathbf{y}^{22}\end{pmatrix} = \begin{bmatrix}\mathbf{L}^{11} & \mathbf{L}^{12}\\ \mathbf{L}^{21} & \mathbf{L}^{22}\end{bmatrix} \begin{pmatrix}\mathbf{y}^{11}+\mathbf{y}^{12}\\ \mathbf{y}^{21}+\mathbf{y}^{22}\end{pmatrix} \tag{2a}$$

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{L}\mathbf{y} \tag{2b}$$

where, $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix.

In order to estimate the CO_2 emissions associated with each region's production, $\boldsymbol{\mu}^{r}$ is defined as the emissions intensity (*r* = Home, Foreign), with a typical element μ_j^r indicating the amount of CO_2 emissions associated with the production of one unit total output in sector *j* (*j* = 1, ..., n) in region *r*. Thus, CO_2 emissions in each region can be formulated as

$$\begin{pmatrix}\mathbf{e}^1\\ \mathbf{e}^2\end{pmatrix} = \begin{pmatrix}\hat{\boldsymbol{\mu}}^1\mathbf{x}^1\\ \hat{\boldsymbol{\mu}}^2\mathbf{x}^2\end{pmatrix} = \begin{bmatrix}\hat{\boldsymbol{\mu}}^1\mathbf{L}^{11} & \hat{\boldsymbol{\mu}}^1\mathbf{L}^{12}\\ \hat{\boldsymbol{\mu}}^2\mathbf{L}^{21} & \hat{\boldsymbol{\mu}}^2\mathbf{L}^{22}\end{bmatrix} \begin{pmatrix}\mathbf{y}^{11}+\mathbf{y}^{12}\\ \mathbf{y}^{21}+\mathbf{y}^{22}\end{pmatrix} = \begin{bmatrix}\mathbf{E}^{11} & \mathbf{E}^{12}\\ \mathbf{E}^{21} & \mathbf{E}^{22}\end{bmatrix} \begin{pmatrix}\mathbf{y}^{11}+\mathbf{y}^{12}\\ \mathbf{y}^{21}+\mathbf{y}^{22}\end{pmatrix} \tag{3}$$

where, $\mathbf{E}^{rs}$ with its typical element e_j^{rs} gives region *r*'s emissions due to the final demand (both intra- and inter-regional) for product *j* from region *r*.

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[4] It is worth noting that input coefficients are different from technical coefficients. They have different interpretations and thus have different uses. Input coefficients depict local inter-industry linkages, whereas technical coefficients give the technological structure (irrespective of whether items are sourced from within the region or from imports). Essentially, the latter term is suitable when discussing technological changes; in contrast, the former term is useful when addressing local direct and indirect impacts, which is just the issue we tackle here.

Intuitively, we can split equation (3) into two equations, in which the production-based accounting principle (see equation (3a)) and the consumption-based accounting principle (see equation (3b)) are explicitly distinguished (see Dietzenbacher et al., 2012). Following the production-based accounting principle, only the producers are held accountable for any emissions associated with the production process; in contrast, following the consumption-based accounting principle, consumers are held responsible for emissions as they consume goods.

$$\begin{pmatrix} \mathbf{e}_p^1 \\ \mathbf{e}_p^2 \end{pmatrix} = \begin{pmatrix} \mathbf{e}^1 \\ \mathbf{e}^2 \end{pmatrix} = \begin{bmatrix} \hat{\boldsymbol{\mu}}^1\mathbf{L}^{11} & \hat{\boldsymbol{\mu}}^1\mathbf{L}^{12} \\ \hat{\boldsymbol{\mu}}^2\mathbf{L}^{21} & \hat{\boldsymbol{\mu}}^2\mathbf{L}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{y}^{11}+\mathbf{y}^{12} \\ \mathbf{y}^{21}+\mathbf{y}^{22} \end{pmatrix} = \begin{bmatrix} \mathbf{E}^{11} & \mathbf{E}^{12} \\ \mathbf{E}^{21} & \mathbf{E}^{22} \end{bmatrix} \begin{pmatrix} \mathbf{y}^{11}+\mathbf{y}^{12} \\ \mathbf{y}^{21}+\mathbf{y}^{22} \end{pmatrix} \tag{3a}$$

$$\begin{pmatrix} \mathbf{e}_c^1 \\ \mathbf{e}_c^2 \end{pmatrix} = \begin{pmatrix} (\hat{\boldsymbol{\mu}}^1\mathbf{L}^{11}+\hat{\boldsymbol{\mu}}^2\mathbf{L}^{21})\mathbf{y}^{11}+(\hat{\boldsymbol{\mu}}^1\mathbf{L}^{12}+\hat{\boldsymbol{\mu}}^2\mathbf{L}^{22})\mathbf{y}^{21} \\ (\hat{\boldsymbol{\mu}}^1\mathbf{L}^{11}+\hat{\boldsymbol{\mu}}^2\mathbf{L}^{21})\mathbf{y}^{12}+(\hat{\boldsymbol{\mu}}^1\mathbf{L}^{12}+\hat{\boldsymbol{\mu}}^2\mathbf{L}^{22})\mathbf{y}^{22} \end{pmatrix} = \begin{pmatrix} (\mathbf{E}^{11}+\mathbf{E}^{21})\mathbf{y}^{11}+(\mathbf{E}^{12}+\mathbf{E}^{22})\mathbf{y}^{21} \\ (\mathbf{E}^{11}+\mathbf{E}^{21})\mathbf{y}^{12}+(\mathbf{E}^{12}+\mathbf{E}^{22})\mathbf{y}^{22} \end{pmatrix} \tag{3b}$$

Both methods have their own uses. As most statistics are production unit based, it is relatively easy and straightforward to obtain relevant data. However, if Home has relatively stringent environmental laws, it is expected that firms may shift to Foreign for production, a phenomenon called the “pollution haven hypothesis” in the literature (see Copeland and Taylor, 2003, for a nice review). In this regard, the consumption-based accounting principle can be an effective alternative to allocate responsibility for emissions (and other pollutants).

2.2 CO_2 emissions embodied in trade

As an accounting identity, CO_2 emissions are the same irrespective of whether a production-based accounting principle or a consumption-based accounting principle is adopted. Clearly, for our hypothetical world with two regions, one region’s net CO_2 emissions embodied in trade equals the other’s net CO_2 emissions embodied in trade (with opposite signs). To facilitate our analysis, take Home region (region 1) as an example. The CO_2 emissions embodied in exports and in imports need to be separately estimated.

First we consider exports:

$$\mathbf{e}_{ex}^{1} = (\mathbf{E}^{11} + \mathbf{E}^{21})\mathbf{y}^{12} + \mathbf{E}^{12}(\mathbf{y}^{21} + \mathbf{y}^{22}) \tag{4}$$

Equation (4) gives CO_2 emissions embodied in exports. Here, we distinguish between final uses and intermediate inputs. Specifically, $(\mathbf{E}^{11} + \mathbf{E}^{21})\mathbf{y}^{12}$ represents the (Home and Foreign) emissions embodied in Home's export of final goods $\mathbf{y}^{12}$ to Foreign; while $\mathbf{E}^{12}(\mathbf{y}^{21} + \mathbf{y}^{22})$ gives emissions embodied in Home's exports of intermediate goods to Foreign, noting that the intermediate goods are used for the satisfaction of final consumption in both regions (i.e., $(\mathbf{y}^{21} + \mathbf{y}^{22})$).

In the same fashion, Home's emissions in embodied imports can be expressed as

$$\mathbf{e}_{im}^{1} = (\mathbf{E}^{22} + \mathbf{E}^{12})\mathbf{y}^{21} + \mathbf{E}^{21}(\mathbf{y}^{11} + \mathbf{y}^{12}) \tag{5}$$

Hence, Home's balance of emissions embodied in trade can be calculated as emissions embodied in exports net of emissions embodied in imports.

$$\mathbf{teb}^{1} = \mathbf{E}^{11}\mathbf{y}^{12} + \mathbf{E}^{12}\mathbf{y}^{22} - \mathbf{E}^{22}\mathbf{y}^{21} - \mathbf{E}^{21}\mathbf{y}^{11} \tag{6}$$

As there are both positive and negative terms, $\mathbf{teb}^{1}$ can be greater than, equal to or smaller than zero. Following the convention of merchandise trade, if $\mathbf{teb}^{1} > 0$, meaning that emissions embodied in exports are greater than emissions embodied in imports, the Home region is called a net emissions outward flowing region (with the surplus emissions embodied in the trade account).

In a similar vein, Foreign's balance of emissions embodied in trade can be estimated. In our illustrative example, it is not difficult to see that the balance of emissions embodied in trade for the two regions has the zero sum property: i.e., $\mathbf{teb}^{1} + \mathbf{teb}^{2} = 0$, or $\mathbf{teb}^{2} = -\mathbf{teb}^{1}$. In fact, the two regions example can be extended to the multi-region (*r* regions) case, where the zero sum property still holds: i.e., $\mathbf{teb}^{1} + \mathbf{teb}^{2} + \cdots + \mathbf{teb}^{r} = 0$.

2.3 Balance of CO_2 emissions embodied in trade

According to standard trade theory (in particular, the HOV model), a region should export those goods that are relatively intensive in using its relatively abundant factors of production and will import goods that are relatively intensive in using its relatively scarce factors of production. In its extended version, the balance of a factor embodied in trade (positive or negative) should have the same sign as a region's comparative advantage (or disadvantage). Specifically, if a region is relatively abundant in labor, then it is expected that the labor content in exports should be greater than that in imports (Davis & Weinstein, 2001).

For simplicity, CO_2 emissions can be considered as one type of "factor",[5] and according to the HOV model, the net CO_2 emissions embodied in trade should be in accordance with the region's comparative advantage (or disadvantage). Define the gross regional product of region *r* to be g^r, so its share can be computed as $g^r / \sum_s g^s$. Further define the endowment *k* in region *r* to be k^r, so its share is calculated as $k^r / \sum_s k^s$. Similarly, the CO_2 emissions in region r are e^r and its share is given by $e^r / \sum_s e^s$.

Following Davis and Weinstein (2001), it is predicted that: $(e^r / \sum_s e^s - g^r / \sum_s g^s) \times teb^r > 0$. In words, this states that if region *r* has a higher share of CO_2 emissions than its share of gross regional product, the region can be considered as a region with relatively abundant CO_2 emissions; thus, it is highly likely that the CO_2 emissions embodied in exports are greater than those in imports (i.e., $teb^r > 0$), and *vice versa*.

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[5] In fact, CO_2 emissions and other pollutants are by-products associated with production processes, not inputs *per se*. Taking into account the positive correlation between energy inputs and emissions, and for the sake of simplicity, the emissions are considered as a "factor". See Davis and Weinstein (2001) for a detailed discussion of the factor content problem in the HOV framework.

3. Data issues

Multi-regional input-output (MRIO) tables have been widely used in measuring CO_2 emissions in trade (see SI, ESR 2009). In general, there are just two types of officially published MRIO tables. One treats a “region” as a country, as in the so-called ICIO (inter-country input-output) tables. WIOD and IDE’s Asian IO tables are the most representative cases. The other type of MRIO table treats a “region” as a domestic province (or sub-national area), like China’s interregional IO tables (IDE, 2003). If our research interest just focuses on a country-to-country relationship or a domestic region-to-region relationship, the information provided by conventional MRIO tables is satisfactory.

However, in order to investigate how China’s regional CO_2 emissions are induced through both domestic and international segments of GVCs, the conventional MRIO tables are no longer enough. We need a new dataset in which China’s domestic regions can be fully embedded in an ICIO table. This is for two main reasons. 1) In most ICIO tables, China is treated as a single entry and there is no information about Chinese domestic regions. 2) In most Chinese interregional IO tables, regional exports and imports are treated as exogenous variables, that is, there is no information about who uses Chinese regional exported goods or where Chinese regional imports come from.

In order to overcome the above shortcomings in the existing MRIO tables, Meng et al. (2013b) used a linear programing method to embed the 2007 China interregional IO table into the WIOD table. As shown in the Appendix, this table is a completely closed IO system with four Chinese domestic regions (Northeast, West, Central and Coast) and four foreign country or country groups (the US, Japan, EU and ROW) consistently linked to each other. The most important information used as a bridge to link these two types of MRIO tables is China’s regional customs data by country of origin and destination. This data is originally based on the Harmonized System (HS) classification. Using the Broad Economic Categories (BEC) recently proposed by the UNSD, HS-based trade is separated into intermediate, final consumption and capital goods. This helps to improve the precision of estimations. The empirical results of this paper are based on this new dataset.

In addition, CO_2 emissions data at the national level come mainly from the original WIOD database. The Chinese regional and sectoral CO_2 emissions data are calculated from the combustion of fuels and industrial processes using the Intergovernmental Panel on Climate Change reference approach (IPCC 2006). To estimate CO_2 emissions, 18 types of combustion of fuels and industrial processes are used in this study: raw coal, cleaned coal, other washed coal, briquettes, coke, coke oven gas, other gas, other coking products, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquid petroleum gas, refinery gas, other petroleum products, natural gas and other energy. Fuel data for 44 industries and 30 provinces were collected for use in this study from the China Energy Statistical Yearbooks and the China Provincial Statistical Yearbooks for the target year.

4. Main results

We will divide our results into three sub-sections. First, we will present stylized facts regarding the economies explicitly shown in the dataset. These will then be connected to endowments theory, which leads to theoretical predictions about the direction of net CO2 emissions flow. Then, the empirical results based on the newly developed dataset are compared with the results of Meng et al. (2013a) and others. Finally, we compare the empirical results with the sign prediction based on the extended environmental endowments theory.

4.1 Stylized facts

Before analyzing the empirical results, it is helpful to study the diversity of China’s regions and other economies.

When dealing with a multiregion, multifactor version of the HOV model, the relative share of a certain factor (in comparison with gross regional product) can be used as an indicator of comparative advantage (see Davis and Weinstein, 2001). In reality, energy inputs, which generate pollutants, are essential components for production. In this sense, pollution associated with production can be considered as an "input" (with negative effects). Thus, it is plausible to derive each region's comparative (dis)advantage by comparing the share of gross regional product and the share of CO_2 emissions in production processes.

Table 1 clearly shows a distinct pattern of comparative advantage between developed economies and others. In fact, the three developed regions of Japan, the USA, and EU27 have shares of CO_2 emissions that are smaller than their shares of gross regional product: for example, 14% CO_2 emissions vs. 29.7% gross regional product for EU27. In contrast, the four regions of China (and ROW) have shares of CO_2 emissions that are greater than their shares of gross regional product: for instance, 9.7% CO_2 emissions vs. 3.5% gross regional product in the China Coast region.

Table 1 Regional characteristics and CO_2 emissions in each region, 2007

	Gross regional product, %	CO_2 emissions (production-based), %	Value added share, %
	$g^r / \sum_s g^s$	$e^r / \sum_s e^s$	
China Northeast	0.6	2.4	37.0
China West	1.2	5.0	40.5
China Central	1.3	4.8	37.1
China Coast	3.5	9.7	29.5
Japan	8.0	4.3	51.1
USA	26.0	18.6	54.8
EU27	29.7	14.0	50.0
ROW	29.8	41.3	50.5
World total	54364.5	25261.7	49.7*

Note: Gross regional product is in 2007 Billion US$; CO_2 emissions in million tons. For value added share, the world total gives an average of the whole world (i.e., the sum of world GDP over the sum of world total inputs for each region).

This novel dataset also enables us to calculate each region's value added share. Surprisingly, regions other than China have value added shares of over 50%; whereas the four regions of China have no more than 41% (falling even as low as 29.5% for China Coast). One reason may be that, for developed economies, the service industry that usually has a high value added share forms a relatively larger share of the economy. More importantly, this observation has implications for development strategy, for instance, regarding the emphasis on service industry development in China's "Twelfth Five-year Plan", which takes into account that service industries have the features of low-carbon and high value-added.

4.2 Empirical results

The previous section gives a descriptive analysis of the nature of each region's comparative advantage in terms of CO_2 emissions. In this section we will focus on the estimation of flows of CO_2 emissions among regions (the four regions of China and the other economies).

It is not difficult to see that from a row-wise reading of Table 2 we can get production-based accounting results (i.e., equation (3a)); while for a column-wise reading, the consumption-based accounting principle is employed (i.e., equation (3b)).[6] Several observations can be made from Table 2.

First, values on the diagonal are the largest for each row, meaning that the biggest share of CO_2 emissions generated from production can be accrued to a region's own final demand. For example, the value 4238.3mt (row 7 and column 7) gives the CO_2 emissions generated in the USA due to final demand in the USA. This result is perfectly intuitive.

Second, along each row, we can calculate each region's own share of responsibility for total emissions from production. Strikingly, China's four regions have shares ranging from 41% (North) to 47% (China Coast)[7], substantially lower than other regions in the world (e.g., the USA

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[6] Note that, due to space constraints, only aggregate results are reported in this paper. Industry level results are available upon request.

[7] It may be argued that, smaller economies tend to be more open. So we calculated the share for China as a whole and it turns out that the share increases to some extent (to roughly 69%). Still this value is far lower than that of developed economies, such as Japan (81%), EU27 (84%), and even lower than for ROW (78%). It should be stressed that, processing trade is not explicitly dealt with in this dataset, which may overstate the extent of foreign dependence (see Dietzenbacher et al., 2012, for a single country study).

has a share of no less than 90%), which means that at least half of emissions are generated due to final demand from other regions. This is a typical result of production sharing and is particularly pervasive in China's regions.

Table 2 Production sharing and CO_2 emissions due to final uses (million tons), 2007

	China Northeast	China West	China Central	China Coast	Japan	USA	EU27	ROW
China Northeast	247.5	39.5	55.0	115.6	16.1	31.6	32.5	67.7
China West	41.6	520.4	154.6	255.7	22.1	64.3	62.7	131.6
China Central	19.8	70.3	542.1	253.5	25.7	77.9	76.8	149.4
China Coast	36.0	128.7	171.6	1161.3	77.0	247.1	215.5	410.8
Japan	1.4	2.2	2.9	19.7	877.3	40.8	33.6	102.3
USA	1.4	2.9	3.0	19.9	26.2	4238.3	113.6	288.2
EU27	3.1	3.7	4.1	26.2	23.9	135.2	2963.3	376.0
ROW	15.1	29.0	34.6	186.9	224.9	826.5	935.5	8177.8

Source: Authors' calculation based on the novel dataset.

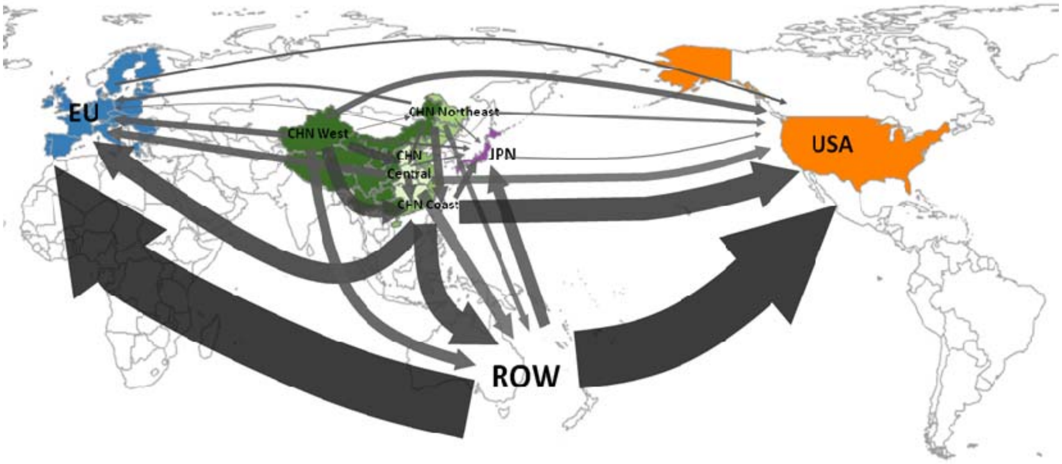
Note: Values in each cell give the CO_2 emissions generated in the regions in the column due to final consumption in regions in the row, and values in diagonal are emissions due to a region's own final demand. For example, the value 115.6 (column five and row two) means to fulfill the final demand in the China Coast region, 115.6mt CO_2 were generated in China Northeast.

Third, when comparing our results with those of Meng et al. (2013a), it is clear that we add new information about regional responsibility for CO_2 emissions. This is valuable in two respects: on the one hand, it is possible to position regions in a global supply chain (the CO_2 emissions chain); on the other hand, the carbon leakage issue can be explicitly tackled.

In terms of industries, two industries top the rank of production-based accounting CO_2 emissions for all four regions of China, namely the *material and process industry* and *construction* (see Appendix 1 for sector classifications). This observation comes as no surprise if we realize that China’s production mix (or GDP composition) is biased towards secondary industry. At the same time, it can be seen that consumption-based CO_2 emissions are mainly due to gross capital formation.

For comparison, the production-based CO_2 emissions in the USA, whose pattern of emissions is different from the rest, came from construction and services. One of the primary reasons would be that the USA has outsourced a substantial amount of production activity. In sharp contrast to China, consumption-based CO_2 emissions in Japan, the USA, EU27 and ROW were all dominated by private consumption. And it is found that, take the USA as an example, her private consumption caused CO_2 emissions in China amounted to 238.6mt (the region with the biggest share of the responsibility was China Coast which contributed 59% of the total).

Figure 1 CO_2 emissions embodied in net exports with China split into regions, 2007



Source: Authors’ compilation based on the novel dataset.

Interestingly, it can be seen from Figure 1[8] that inland regions (say, China West and China Central) also have massive CO_2 emissions embodied in net exports to EU27, the USA and ROW. In fact, these inland regions do not export a lot of goods and service to foreign countries

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[8] We are indebted to Miao Yu from Tsinghua University for providing assistance in preparing the Figure.

directly, particularly when compared with coastal regions. However, indirectly, they have been deeply involved in GVCs. One of the most plausible interpretations would be because they are located relatively upstream along the production chain and thus provide huge amounts of intermediate goods and natural resources (normally with high-carbon intensity) to downstream and exporting regions (i.e., China Coast). It can be seen that these intermediate goods are embodied in final goods assembled and produced in China Coast and ultimately exported to EU27, the USA and ROW. This observation helps to explain why inland regions also export (albeit in an indirect manner) large amounts to foreign economies. In other words, inland regions within a country can also join GVCs via an indirect route.

At the same time, more emissions may be generated to fulfill foreign demand since environmental regulation in China's inland regions tends to be weaker.[9] In this regard, common but differentiated responsibilities should also be proposed at a regional level within one country, e.g. China. Specifically, inland regions should implement the same stringent environment regulations that are in place elsewhere and, to remedy the downsides of relatively poor technology, a certain amount of technology transfer or even monetary aid from coastal regions needs to be in place (similar to the so-called Clean Development Mechanism, or CDM, in a global context). Such an arrangement is relatively easy in China; the main advantage is that there is central government which can design policy to motivate regional actions. In fact, some movement, albeit partial, in this direction has been observed (e.g., there are seven pilot cities or provinces in the Emissions Trading System, or ETS). To achieve a nation-wide goal of CO_2 emissions reduction, interregional carbon leakage needs to be taken fully into consideration.

It can also be seen from Figure 1 that China's interregional carbon leakage is remarkable: in particular, inland regions (e.g., Northwest) export substantial amounts of CO_2 emissions to

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[9] Fortunately, the USA and China, two giant emitters in the world, jointly announced respective targets for CO_2 emissions reduction during the APEC Summit held in Beijing, 2014. China aims to reach the peak of absolute CO_2 emissions in 2030 at the latest, while the USA promises to reduce CO_2 emissions intensity by about 25%-28% in 2025 relative to the 2005 level. To achieve these ambitious goals, empirical studies and careful policy recommendations are needed, for example, identifying the main sources for CO_2 emissions will help to fix policy priorities.

coastal regions. If the ETS only covers intra-region emissions trading and production activities within a region, then only part of the story is revealed. Ideally, a nationwide ETS market should be formed, and by designing a national goal for CO_2 emissions reduction, a top-down approach can be adopted to allocate the national reduction at the regional level. Then, through the national CDM, inland regions will also benefit from stringent environmental regulations. This is also relevant for global climate change policy, although perhaps to lesser extent—since there is no "central government" above all sovereign economies, a binding agreement is not easy to obtain. Luckily, by employing the "transnational and interregional" framework, our novel data can provide empirical evidence to support such efforts.

4.3 Balance of CO_2 emissions embodied in trade

The basic idea of the sign test for balance of CO_2 emissions embodied in trade is straightforward: it states that the sign of one economy's percentage share of a factor *minus* its percentage share of world GDP equals the sign of that economy's factor content of net exports.

Table 3 Comparative advantage, CO_2 emissions embodied in trade and empirical test, 2007

	Relative CO_2 emissions abundance, %	CO_2 emissions embodied in exports	CO_2 emissions embodied in imports	Empirical test
China Northeast	1.8	358.1	118.5	+
China West	3.8	732.6	276.3	+
China Central	3.5	673.4	425.7	+
China Coast	6.2	1286.7	877.5	+
Japan	-3.7	202.9	416.0	+
USA	-7.4	455.3	1423.2	+
EU27	-15.7	572.1	1470.3	+
ROW	11.5	2252.5	1526.1	+

Note: CO_2 emissions embodied in trade are in million tons.

Table 3 gives the results of this sign test. The second column is obtained by taking the difference of column three (share of CO_2 emissions) and column two (share of world GDP) in

Table 1, which can be used as a proxy for comparative advantage. By using equations (3a) and (3b), the amounts of CO_2 embodied in exports and in imports are estimated (columns three and four). The last column gives the results of the sign test, i.e., the sign of each region's CO_2 content of net exports (column three *minus* column four) times the sign of that region's relative CO_2 abundance (column two).

It seems that the environmental version of the HOV model performs fairly well, which is confirmed by the data (see the positive signs in the last column).[10] This relates to recent discussion regarding the so-called "Green Leontief Paradox" (see Dietzenbacher and Mukhopadhyay, 2007), for which we do not find any support. In other words, in general, the validity of the extended environmental HOV model is supported by our study. This is an important message, meaning that we can explain and even predict the flows of CO_2 emissions in such a theoretical framework. We suspect that this result holds not only for CO_2 emissions but also for other pollutants.

Furthermore, our results are relevant to the debate about the "pollution haven hypothesis" and the "factor-endowment hypothesis" (see Temurshoev, 2006; Copeland and Taylor, 2004). Evidently, the factor (as well as pollutant) content of net exports depends largely on the economy's endowments (relative abundance or scarcity). In this regard, structural changes or upgrading production technology within each region are the best choice for climate change mitigation.

5. Conclusion and discussion

Production sharing is a major characteristic of today's economy. It is thus relevant to consider CO_2 emissions embodied in trade in the context of global value chains (GVCs) even if the focus is on domestic regions. This paper considers a novel dataset describing eight regions and eight sectors for year 2007. The dataset covers four regions of China, together with Japan, the USA,

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[10] The results shown here include interregional flows within China. We have conducted similar analysis excluding interregional flows within China (which can be readily checked by simple calculations using Table 2). The conclusions still hold.

the EU27 and ROW. A demand spillover perspective is adopted to allocate emissions responsibilities between producers and consumers so that CO_2 emissions embodied in trade can be estimated. The empirical results were interpreted using an extended environmental HOV model, and an empirical test was performed. Strikingly, the directions of CO_2 emissions embodied in net exports were entirely predicted by our theoretical framework.

In particular, the four regions of China are upstream regions in the GVCs and are endowed with energy inputs (thus CO_2 emissions); therefore, their exports were CO_2 emissions intensive. This observation holds also for China as a whole. Within China, it is also clear that, China Coast was relatively downstream, in a position of importing CO_2 emissions from the rest of China. These findings are relevant to the current debate on the “pollution haven hypothesis” and the “factor endowment hypothesis”. It seems factor endowments are the ultimate determinants of the pattern of factor content (either CO_2 emissions or other factors) in net exports.

In terms of policy discussions, input structure and production technology play crucial roles in determining the pattern of trade and, given a technology, factor endowments are fundamental determinants of the production pattern. This is old wisdom that has been around since the beginning of the Heckscher-Ohlin theorem. What is new here is that our paper confirms such predictions in a broader sense and provides a micro interpretation of empirical findings. In this regard, the policy recommendation would be to target micro mechanisms that determine the comparative advantage. For instance, a tax reform for coal from the amount levied to an *ad valorem* fashion will change the relative price of energy inputs and thus have an impact on the input choice of producers, which will eventually change the emissions content in production.

Equally important is that a nationwide ETS is urgently called for, given the fact that interregional carbon leakage is severe. To remedy the downside of poor technology found in inland regions, technology transfer or monetary redistribution should be implemented by central government. This would help to achieve the CO_2 emissions peak as early as possible and it is believed that unilateral movement towards a low-carbon economy is also beneficial to the global environment.

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Appendix 1 Sector classification

		Sector classification used in the paper							
		1	2	3	4	5	6	7	8
Code	**Sectors in China's MRIO table**	Agriculture	Mining and quarrying	Life-related industry	Process industry	Assembly Industry	Electricity, Gas and Water Supply	Construction	Other services
1	Agriculture	✓							
2	Mining and quarrying		✓						
3	Food products and tobacco			✓					
4	Textile and garment			✓					
5	Wooden products and furniture				✓				
6	Pulp, paper and printing				✓				
7	Chemical				✓				
8	Non-metallic mineral products				✓				
9	Metal products				✓				
10	General mechinary					✓			
11	Transport equipment					✓			
12	Electric apparatus, electronic and telecommunications equipment					✓			
13	Other manufacturing products			✓					
14	Electricity, gas, and water supply						✓		
15	Construction							✓	
16	Trade and transportation								✓
17	Other services								✓
Code	**Sectors in WIOT**								
1	Agriculture, Hunting, Forestry and Fishing	✓							
2	Mining and Quarrying		✓						
3	Food, Beverages and Tobacco			✓					
4	Textiles and Textile Products			✓					
5	Leather, Leather and Footwear			✓					
6	Wood and Products of Wood and Cork				✓				
7	Pulp, Paper, Paper , Printing and Publishing				✓				
8	Coke, Refined Petroleum and Nuclear Fuel				✓				
9	Chemicals and Chemical Products				✓				
10	Rubber and Plastics				✓				
11	Other Non-Metallic Mineral				✓				
12	Basic Metals and Fabricated Metal				✓				
13	Machinery, Nec					✓			
14	Electrical and Optical Equipment					✓			
15	Transport Equipment					✓			
16	Manufacturing, Nec; Recycling					✓			
17	Electricity, Gas and Water Supply						✓		
18	Construction							✓	
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel								✓
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles								✓
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods								✓
22	Hotels and Restaurants								✓
23	Inland Transport								✓
24	Water Transport								✓
25	Air Transport								✓
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies								✓
27	Post and Telecommunications								✓
28	Financial Intermediation								✓
29	Real Estate Activities								✓
30	Renting of M&Eq and Other Business Activities								✓
31	Public Admin and Defence; Compulsory Social Security								✓
32	Education								✓
33	Health and Social Work								✓
34	Other Community, Social and Personal Services								✓
35	Private Households with Employed Persons								✓

Appendix 2 Country and Chinese domestic region classification

Countries in WIOT	Countries or country-group used in the paper				
	CHN	JPN	USA	EU	RoW
AUS					✓
AUT				✓	
BEL				✓	
BGR				✓	
BRA					✓
CAN					✓
CHN	✓				
CYP				✓	
CZE				✓	
DEU				✓	
DNK				✓	
ESP				✓	
EST				✓	
FIN				✓	
FRA				✓	
GBR				✓	
GRC				✓	
HUN				✓	
IDN					✓
IND					✓
IRL				✓	
ITA				✓	
JPN		✓			
KOR					✓
LTU				✓	
LUX				✓	
LVA				✓	
MEX					✓
MLT				✓	
NLD				✓	
POL				✓	
PRT				✓	
ROM				✓	
RUS					✓
SVK				✓	
SVN				✓	
SWE				✓	
TUR					✓
TWN					✓
USA			✓		
RoW					✓

Provinces in China	Region classification used in the paper			
	NorthEast	West	Center	Coast
Beijing				✓
Tianjin				✓
Hebei				✓
Shanxi			✓	
Neimenggu		✓		
Liaoning	✓			
Jilin	✓			
Heilongjiang	✓			
Shanghai				✓
Jiangsu				✓
Zhejiang				✓
Anhui			✓	
Fujian				✓
Jiangxi			✓	
Shandong				✓
Henan			✓	
Hubei			✓	
Hunan			✓	
Guangdong				✓
Guangxi		✓		
Hainan				✓
Chongqing		✓		
Sichuan		✓		
Guizhou		✓		
Yunnan		✓		
Tibet		✓		
Shaanxi		✓		
Gansu		✓		
Qinghai		✓		
Ninxia		✓		
Xinjiang		✓		